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(71) Applicant: TEXAS INSTRUMENTS INCORPORATED
Dallas Texas 75265 (US)

(72) Inventor: Tregilgas,John H.
Richardson, TX 75081 (US)

(74) Representative: Schwepfinger, Karl-Heinz, Dipl.-Ing.
Prinz & Partner,
Manzingerweg 7
D-81241 München (DE)

(54) Improvements in or relating to micromechanical devices

(57) An electrically addressable, integrated, monolithic, micromirror device (10) is formed by the utilization of sputtering techniques, including various metal and oxide layers, photoresists, liquid and plasma etching, plasma stripping and related techniques and materials. The device (10) includes a selectively electrostatically deflectable mass or mirror (12) of supported by one or more beams (18) formed by sputtering and selective etching. The beams (18) are improved by being constituted of an electrically conductive, intermetallic aluminium compound, or a mixture of two or more such compounds. The materials constituting the improved beams (18) have relatively high melting points, exhibit fewer primary slip systems than FCC crystalline structures, are etchable by the same or similar etchants and procedures used to etch aluminium and aluminium alloy, and are stronger and experience less relaxation than aluminium or aluminium alloys. Accordingly, the improved beams (18) exhibit increased strength, and decreased relaxation without requiring significant or radical deviations from the typical processing steps employed to produce the otherwise unaltered device.

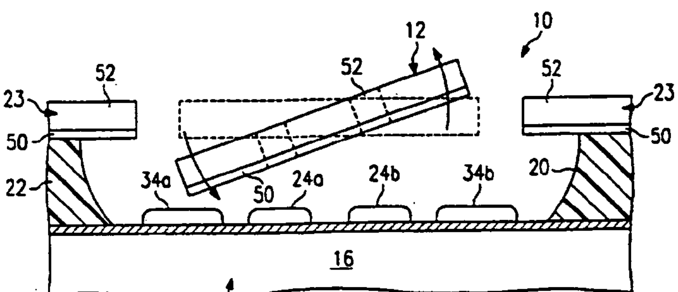

FIG. 2

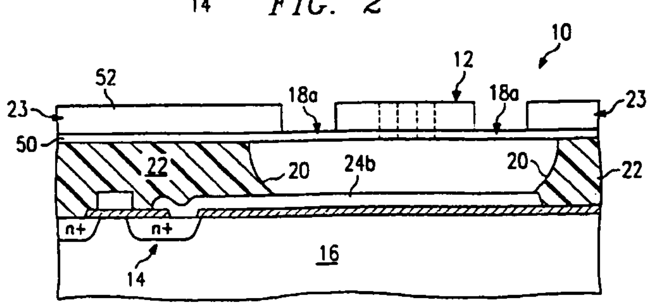

FIG. 3

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Description

FIELD OF THE INVENTION

The present invention relates to a micromechanical device having an improved beam, and, more particularly, to a micromirror device having an improved beam or hinge-like member. The present invention specifically relates to an electrically addressable, integrated, monolithic, micromirror device, the electrical and mechanical elements of which may be formed by the utilization of sputtering techniques, various metal and oxide layers, photoresists, liquid and plasma etching, plasma stripping and related techniques and materials. A selectively electrostatically deflectable mirror of which the device is supported by one or more improved hinge-like cantilever and/or torsion beams formed by sputtering and selective etching, which beams exhibit increased strength, and decreased relation without requiring significant deviations from the typical processing steps employed to produce the otherwise unaltered device.

BACKGROUND OF THE INVENTION

Various types of micromechanical devices are known. Such devices include micromechanical spatial light modulators ("SLMs") having pixels formed of electrically addressable, deflectable mirrors or reflectors. SLMs are transducers capable of modulating incident light in correspondence to an electrical and/or optical input. SLMs are capable of modulating the incident light in phase, intensity, polarization, and/or direction.

The present invention relates to SLMs of the foregoing type which are called digital micromirror devices or deformable mirror devices ("DMDs"). SLM DMDs of the type involved herein may be used in a variety of devices, such as printers, imaging systems, xerographic reproduction systems and digitized video systems. See commonly assigned US Patents, 4,728,185, 5,101,236 and 5,079,544 and published EP Pat No. 0,433,985.

Commonly assigned US Patents 5,061,049 and 5,096,279 (hereinaft,r "'049" and "'279") disclose the structure of, and methods of producing, preferred micromechanical devices, specifically DMD SLMs. In general, micromechanical devices typically include a deflectable or movable mass supported by a deformable beam. According to '049, a DMD SLM may include an array or matrix of relatively thick, generally planar, metal mirrors or reflectors, constituting the "mass." Each mirror comprises a layer of aluminium or an aluminium alloy, such as Al (98.5-98.8%):Si(1%):Ti(0.2-0.5%) which is formed by sputtering and selective etching.

The mirrors reside on a relatively thin layer similarly constituted and also formed by sputtering and selective etching. Each mirror is supported by one or more beams. The beams comprise portions of the relative thin layer which extend beyond the boundary of each mirror and are, in turn, ultimately supported by one or more spacers or posts which may be constituted of a photoresist or a metal. The spacers or posts define or are separated by wells beneath the mirrors and into and out of which the mirrors may move when they are selectively deflected. The spacers or posts and the wells are, in turn, formed by selective deposition and removal or patterning of metal, insulative and photoresist laminae.

An undeflected DMD mirror may occupy a normal position which may be "horizontal," that is, above its well and generally parallel to a substrate on and in which the DMD is formed. Each normally positioned mirror reflects light incident thereon to a first destination. The mirror is selectively deflectable out of its normal position by the selective application thereto of a predetermined electrostatic attractive or repulsive force. A deflected mirror may be "non-horizontal" or rotated out of the horizontal. Each deflected mirror modulates light incident thereon by reflecting the light to a second destination which depends on the amount of deflection and, accordingly, the presence and/or strength of the applied electrostatic force.

Movement of a mirror out of its normal position deforms its beam(s), storing potential energy therein. The stored potential energy tends to return the mirror to its normal position once the electrostatic force is removed. The beam(s) supporting a mirror may deform in a cantilever mode, in a torsional mode, or in a combination of both modes, called the flexure mode.

The selective electrostatic deflection of the mirrors of an array or matrix thereof is selectively effected by a congruent array or matrix of electrodes located on or in the substrate and on or at the bottoms of the wells. Selected electrostatic force-producing voltages are selectively applied to the electrodes by MOSFET or functionally similar elements and associated electrical components associated with the electrodes. These circuit elements and components are typically formed on and in the substrate by traditional integrated circuit manufacturing processing techniques. Specifically, the MOSFETS or other elements and their associated components, as well as the mirrors, beams, posts or spacers and electrodes are preferably integrally, monolithically formed by typical CMOS or similar techniques in and on a silicon or other substrate.

Extensive testing and analysis of the above-described type of micromechanical device has indicated that the strength of the beams is not sufficiently great to resist relaxation --a phenomenon also known as "creep" or "deformation"-- thereof following sustained usage. Such relaxation of the beams results in improper operation of micromechanical DMD SLMs and other similar micromechanical devices. For example, a relaxed beam may be incapable of maintaining its mirror in, or returning its mirror to, the normal position when there is no attractive electrostatic force applied thereto. In a non-normal position, the mirror may reflect incident light to other than the first or second destinations. Thus, relaxation of beam leads to unintended modulation of incident light. Additionally, even if relaxation does not result in a mirror not properly returning to its normal position, relaxation of the

mirror's beam(s) can result in the mirror not deflecting by the appropriate amount upon the application of the predetermined voltage to the applicable electrode. Again, improper modulation of incident light results.

Beams which are stronger than those consisting of aluminium alloys and which are less subject to relaxation are known. For example, early developed SLMs related to the type described above utilized beam-like members comprised of silicon oxide. See US Patents 4,356,730, 4,229,732 and 3,886,310. It has also been generally proposed to fabricate the beam(s) of DMD mirrors from materials stronger than, and less subject to relaxation or creep than, the aluminium alloy described above. The use of such materials carries with it, however, the likelihood that the processing sequences and materials (e.g. etchants) presently used to fabricate DMDs, including their addressing circuitry and mechanical elements, would require substantial or radical modification, possibly adding to the complexity of processing resulting in a concomitant increase in the cost of producing DMDs.

Another proposal involves fabricating beams with multiple laminae of aluminium or aluminium alloy alternating with laminae of a stronger, less ductile material, such as alumina. The outer laminae are aluminium or aluminium alloy, so that the majority of the processing steps involving etching remain the same as those described above to produce the traditional DMD structure. Because the alternating laminae are produced by periodically interrupting sputter deposition of the aluminium or aluminium alloy and sputter depositing the stronger, less ductile material, the process is complicated to that extent, and production costs may be increased.

A desiderata of the present invention is the provision of micromechanical devices, such as DMD SLMs, having beams which are stronger and relaxation-resistant, the beams being fabricated without substantially or radically increasing the complexity or cost of the DMD processing sequence.

SUMMARY OF THE INVENTION

According to the present invention, there is provided an improved deformable beam for a micromechanical device. The device includes a deflectable mass supported by the beam. deflection of the mass deforms the beam. In preferred embodiments, the micromechanical device is a DMD SLM, and the mass is a movable or deflectable mirror which selectively modulates incident light as the mirror deflects.

The improved beam may be characterized in one or more of the following ways:

The beam is constituted of one or more aluminium compounds which are electrically conductive

The beam is constituted of an aluminium compound of the general formula Al_XQ_Y, where Q is not oxygen, the compound having a relatively high melting point and exhibiting fewer primary slip systems than the twelve primary slip systems of FCC crystalline structures

In the previous characterization, Q is gold, calcium, copper, iron, hafnium, magnesium, niobium, nickel, scandium, cobalt, tantalum, zirconium, barium, molybdenum, strontium, tungsten, rutheium, vanadium, chromium, iridium, rhodium, lithium, antimony, titanium, cerium, gadolinium, holmium, lanthanum, lutetium, neodymium, samarium, terbium, selenium, carbon, arsenic, boron, phosphorus or nitrogen

The beam is constituted of an electrically non-insulative material selected from the group consisting of an electrically conductive aluminium intermetallic compound or a mixture of two or more such aluminium compounds

In the previous characterization, the material is Al_2Au, Al_2Ca, Al_2Cu, Al_3Fe, Al_3Hf, Al_3Mg_2, Al_3Nb, Al_3Ni, Al_3Sc, Al_3Ta, Al_3Zr, Al_4Ba, Al_4Mo, Al_4Sr, Al_4W, Al_6Ru, Al_7Cr, Al_8V_5, Al_9Co_2, Al_9Ir_2, Al_9Rh_2, AlLi, Al_3Ti, AlTi, AlSb, AlAs, AlP, AlN, Al_3Ce, Al_3Gd, Al_3Ho, Al_3La, Al_3Lu, Al_3Nd, Al_3Sm, Al_3Tb, Al_2Se_3, Al_4C_3, AlB_2, AlTi+Al_3Ti, and Al_3Ti+AlN

The beam is constituted of an electrically conductive material selected from the group consisting of intermetallic compounds which include aluminium, compound semiconductors which include aluminium, compounds which include aluminium and a rare earth, and compounds which include aluminium and a non-metal.

In all of the above characterizations, beams so constituted are stronger and experience less relaxation than prior art beams, especially those made of aluminium or aluminium alloys. Because the improved beams include aluminium, typical or expediently modified aluminium etching chemistries and procedures may be advantageously used. Further, the beams are electrically conductive, thus permitting appropriate potentials to be applied to the mirrors via the beams, as occurs in typical prior art DMDs.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be further described, by way of example, with reference to the accompanying drawings in which;

Figure 1 is a plan view of a portion of an array of DMD SLM-type micromechanical devices illustrating the movable or deflectable masses or mirrors thereof supported by deformable torsion beams which are constituted and fabricated in accordance with the principles of the present invention;

Figure 2 is a partially sectioned side view of a single DMD taken generally along line 2-2 in Figure 1;

Figure 3 is a partially sectioned side view of the DMD shown in Figure 2 and taken generally along line 3-3 in Figure 1;

Figure 4 contains plan views of a variety of DMD SLMs functionally similar to those shown in Figures 1-3, wherein Figure 4a depicts four types of torsion

beam DMDs, Figure 4b depicts two types of cantilever beam DMDs, and Figure 4c depicts one type of flexure beam DMD, the beams of all of the foregoing DMDs advantageously being constituted and fabricated according to the principles of the present invention; and

Figure 5 contains side views of two different types of cantilever beam DMDs, Figure 5a depicting such a DMD having a photoresist spacer supporting a cantilever beam and Figure 5b depicting a metal post supporting a cantilever beam, all of the beams therein being conveniently constituted and fabricated pursuant to the teachings of the present invention.

DETAILED DESCRIPTION

Referring first to Figure 1, there are shown a plurality of micromechanical devices in the form of adjacent, individual DMD's 10, which may be of the type shown in commonly assigned US Patents 5,061,049 to Hornbeck and 3,600,798 to Lee. The DMD's 10 may also be similar to those shown in US Patents 4,356,730 to Cade, 4,229,732 to Hartstein et al, 3,896,338 to Nathanson et al, and 3,886, 310 to Guldberg et al. The DMDs 10 may be located in an array as depicted in Figure 1 and may be used in systems such as those shown and described in commonly assigned US Patents 5,101,236 to Nelson et al, 5,079,544 to DeMond et al, Published European Patent 0,433,985 to Nelson, and US Patents 4,728,185 to Thomas. In the following Description, the DMDs 10 are described as operating in a bistable or digital mode, although they may be operated in other modes, such as tristable or analog.

As generally depicted in Figure 1-3, each DMD 10 includes a selectively movable or deflectable mass, which in the case of the DMDs 10 comprises a relatively thick and massive, metal or metallic light-reflective, movable or deflectable mirror 12 and associated addressing circuits 14 (only two of which are shown) for selectively electrostatically deflecting the mirrors 12. Methods of monolithically forming an array of mirrors 12 and their addressing circuits 14 in and on common substrate 16 are set forth in the above-noted patents. Of course, micromechanical devices other than the DMDs 10 depicted and described in detail herein may advantageously utilize the principles of the present invention.

Typically, each mirror 12 deflects by moving or rotating on one or more relatively thin, integral supporting beams or hinges 18. Although Figure 1 illustrates each mirror 12 being supported by a pair of diametrically opposed torsion beams 18a, the mirrors 12 may be supported by one or more cantilever beams 18b --two types are shown in Figure 4b-- or flexure beams 18c --one type is shown in Figure 4c-- as discussed earlier. Figure 4a depicts four types of torsion beam-supported DMDs 10.

Undercut wells 20 (not shown in Figure 1) are defined between columnar members 22, which may comprise residual photoresist remaining on the substrate 16 afier functioning as a portion of a etching, deposition, and/or implantation mask during the formation of the DMD 10. The beams 18 and metallic portions 23 which surround the mirrors and beams 10 and 12 and are generally coplanar with the mirrors 12 are supported by the members 22.

Each well 20 accommodates the deflection thereinto of at least a portion of its associated mirror 12 by permitting that portion to move toward the substrate 16, as shown by the directional arrows in Figure 2, from an undeflected or normal position, shown Figure 3. Deflection of each mirror 12 is effected by the attractive or repulsive electrostatic forces exerted thereon by electric fields which result from the application of appropriate potentials to the mirrors 12 and to associated control or addressing electrodes 24 located in the wells 20. The potentials are selectively applied to the control electrodes 24 and the mirrors 12 by the addressing circuits 14 and associated circuitry and circuit elements. Typically, the mirror 12 is at ground potential while selected voltages are applied to the control electrodes 24, thereby exerting an attractive force on the mirrors 12. Repulsive forces may be applied to the mirrors 12 by applying potentials of the same polarity to the mirrors 12 and their control electrodes 24.

When a beam 18 is undeformed, it may set the normal position of its mirror element 12, as shown in Figure 3 and in outline in Figure 2. When the beam 18 is deformed, it stores therein energy which tends to return the mirror 18 to the position it occupies when the beam 18 is undeformed. Light which is incident on the device 10 when a mirror element 12 is in its normal position is reflected to a first site. When an addressing circuit 14 applies appropriate potentials, its mirror 12 is electrostatically attracted or repelled out of its normal position toward or away from the control electrode 24 and the substrate 16. The mirror element 12 accordingly moves or deflects until it engages a landing electrode position 34.

The use of the landing electrode 34 is recommended by the aforenoted '279 patent. Specifically, the landing electrode 34 is maintained at the same potential as the mirror 12 and serves as a mechanical stop for the mirror element 12, thus setting the deflected position thereof Further, the engagement of the landing electrode 34 and the mirror element 12 prevents the mirror element 12 from engaging the control electrode 24. Because of the potential difference between the mirror element 12 and the control electrode 24, such engagement would result in current flow through the mirror element 12. Current flow of this type is likely to weld the mirror element 12 to the control electrode 24 and/or to fuse or melt the relatively thin beam 18.

In the deflected position of the mirror element 12, the incident light is now reflected to a second site. The first site to which light is directed when a mirror 12 is undeflected may be occupied by or constitute a utilization device, such as a viewing screen or a photosensitive

drum of a xerographic printing apparatus. The light directed to the second site may be absorbed or otherwise prevented from reaching the first site. The roles of the first and second sites may, of course, be reversed. In the foregoing way, incident light is modulated by the DMDs 10 so that it selectively either reaches or does not reach whichever site contains the utilization device.

In Figures 1-3, each mirror 12 is shown to be associated with a pair of control electrodes 24a,24b and a pair of landing electrodes 34a,34b. When the DMDs 10 are operated in a binary or bistable mode, as described above, each mirror 12 may be movable only between the normal, undeflected position represented in outline in Figure 2, and a counterclockwise rotated position, as shown in Figure 2. Although not depicted in Figure 2, counterclockwise rotation of the mirror 12 occurs until the mirror 12 engages or contacts the left-hand landing electrode 34a. If the mirror 12 is at the preferred ground potential, counterclockwise rotation of the mirror 12 may be effected by the application of a voltage to the left-hand control electrode 24a by the addressing circuitry 14. In this latter event, the right-hand control and landing electrodes 24b and 34b may be eliminated or unused.

If the mirror 12 is rotated by electrostatic repulsion, it and the right-hand control electrode 24b will carry same polarity potentials to achieve the counterclockwise rotation shown in Figure 2. In this event, the left-hand control electrode 24a and the right-hand landing electrode 34b may be eliminated or unused.

The DMDs may also be operated in a binary mode in which the mirror 12 is rotatable between a normal, fully counterclockwise position and a fully clockwise position in which the mirror 12 engages the right-hand landing electrode 34b. When operated in this fashion, the undeformed beam 18 does not set the normal position of the mirror 12. Further, with the mirror 12 at ground potential, the mirror 12 is fully counterclockwise rotated by a potential on the control electrode 24a; the potential on the control electrode 24b has a very low magnitude or is zero. The mirror 12 is rotated fully clockwise to abut the right-hand landing electrode 34b by an appropriate potential on the control electrode 24b, with the potential on the control electrode 24a being zero or nearly so.

In a further binary operational permutation in which the mirror 12 is not at ground potential, voltages of different polarities and/or magnitudes may be simultaneously applied to the control electrodes 24a,24b to simultaneously attract and repel complementary portions of the mirrors 12 for selective rotation thereof. Tristable operation is achieved by rotating the mirrors 12 fully counterclockwise or fully clockwise, with the mirrors occupying a normal intermediate position set by the undeformed beam when the control electrodes 24a,24b are both deenergized. Analog operation is achieved by selected amounts of counterclockwise and/or clockwise rotation of the mirrors 12 through the application to the control electrodes 24a,24b of potentials having appropriate magnitudes. In analog operation, full rotation of the mirrors 12, characterized by engagement of the landing electrodes 34a,34b, is only one of a theoretically infinite number of rotated positions which the mirrors 12 may occupy.

Figure 4a illustrates a variety of DMDs in which the mirrors 12 are supported by torsion beams 18a, including, at the upper right, the variety generally shown in Figures 1-3. As described above, mirrors 12 supported by torsion beams 18a are selectively rotatable on the beams 18a about an axis 40 which is coincident with the beams 18a. The axis 40 of rotation is coincident with an axis of symmetry of the mirror 12 in all but the lower right rendition, wherein the axis 40 is not so coincident. In Figure 4b, the beams 18 are cantilever beams 18b, and the mirrors 12 are movable or deflectable about an axis 42 of rotation which is normal to the beams 18b. Though not shown in Figures 4a and 4b, as should be apparent, the control electrodes 24 must be asymmetrically located relative to the axes 40 and 42 of rotation.

In Figure 4c the beams 18 are so-called flexure beams 18c which deform in both torsional and cantilever modes upon movement of the mirrors 12. Specifically, each flexure beam 18c includes a torsionally deformable element 44 and an element 46 which is deformable in a cantilever mode. Upon attraction of the mirror 12 to or repulsion of the mirror 12 from the control electrode 24 the mirror 12 moves piston-like by remaining generally parallel to the substrate 16.

Returning to Figures 1-3, it may be seen that each mirror 12 may include two or more layers, such as the metallic layers 50 and 52 which are shown. These layers 50,52 may be selectively deposited and patterned or etched pursuant to, and in the course of carrying out, typical procedures used to manufacture monolithic integrated circuits. In this way, the mirrors 12, beams 18 and control circuitry 14 may all be produced by a continuous series of interrelated process steps. In the past both of the layers 50,52 have comprised an alloy of Al:Ti:Si in the percent ratio of about 98.8:1:0.2, with the layer 50 being from about 500Å to about 1000 Å thick and the layer 52 being from about 3,000Å to about 5000 Å thick, although other thicknesses have been used. Either layer 50,52 may be another aluminium alloy or aluminum.

To fabricate DMDs, the relatively thin layer 50 is first deposited, typically be sputtering, on the free surface of a previously deposited, continuous layer of the photoresist 22. The relatively thicker layer 52 is then deposited on the free surface of the layer 50. Selective patterning of the layers 50 and 52 removes the thicker layer 52 but not the thinner layer 50 where beams 18 are to reside and removes both layers 50 and 52 where the peripheries of the mirrors 12 and the beams 18 are to reside. Between these peripheries and the surrounding regions 23 there are defined access gaps 54. Selective patterning of the layers 50,52 also produces access holes 56 through both thereof Selective removal of the photoresist 22, as by plasma etching thereof through the access gaps and holes 54,56, produces the wells 20.

In some embodiments, it may, as noted above, be preferred for the support of the beams 18 and their mir-

rors 12 to be achieved by the columnar photoresist 22 which remains after formation of the wells 20. Figure 5a illustrates this type of support in a cantilever-beam 18b DMD 10, instead of the torsion-beam 18a DMDs 10 of Figures 1-3. Figure 5b illustrates a somewhat differently constructed hidden-hinge, cantilever-beam 18b DMD 10, in which support for the beam 18b and the mirror 12 is provided by a metallic post 58 which suspends the mirror 12 over an open area 60 which serves the same function as the well 20. Figures 35a-35e of the '049 patent illustrate a first method of manufacturing DMDs 10 of the type shown in Figures 1-4 and 5a hereof. In those Figures of the '049 patent, the layer 326 is a sputtered light aluminium layer which ultimately serves as a beam 18 and a sputtered light aluminium layer 328 ultimately forms the reflective mirror 12. In the same patent, Figures 40a-40e illustrate an alternative method for forming the DMDs 10 of the present invention in which the beams 18 are produced from a sputtered light aluminium alloy layer 180 and the mirrors 12 are produced from a sputtered light aluminium layer 190.

When a mirror 12 is in a deflected position, its beam 18 is deformed and, accordingly, stores energy therein which tends to return the mirror element 12 to the position it occupies when the beam 18 is undeformed. In theory, when the control electrode 24 is de-energized by the addressing circuit 14, the stored energy will return the mirror element 12 to this position.

DMDs 10 of the above-described types have been extensively operated and tested. Such testing indicates that DMDs 10 may experience improper operation or fail to operate due to several causes.

One cause of improper operation or failure of DMDs 10 is discussed in commonly assigned Published European Patent 0,433,985. Specifically, the mirror 12 and the landing electrode 34 which are engaged during deflection of the former may become adhered, welded or otherwise stuck together so that simple de-energization of the control electrode 24 may not result in the mirror element 12 returning to the position it occupies when the beam 18 is undeformed. Special reset signals may be applied to the control electrode 28 which overcome the sticking or adhering together of the mirror element 12 and the landing electrode 34. Other techniques for preventing the mirror elements 12 and the landing electrodes 34 from sticking include coating these elements with appropriate substances.

Another cause of improper operation or failure of DMDs 10 relates to the fact that their beams 18 have typically comprised the layer 50 of aluminium alloy. The aluminium alloy exhibits a relatively low yield stress, and beams 18 fabricated therefrom deform over time due to creep, relaxation or deformation. These phenomena may result in catastrophic failure or breakage of a beam 18 or in a mirror 12 being positioned in other than the position dictated by the condition of its addressing circuitry 14.

The present invention replaces the layer 50 of Al:Ti:Si or other aluminium alloy with aluminium compounds which are more mechanically robust and which exhibit fewer primary slip systems than the twelve primary slip systems of the face-centered-cubic ("FCC") crystalline structure of aluminium or the previously used aluminium alloy. These aluminium compounds permit the use of the same or expediently modified deposition/etch materials and chemistries as have been used with the prior aluminium alloy. Even though some modification is necessary, unlike more robust non-aluminium materials, the modified chemistries do not require radical departure from time-tested and well understood procedures related to aluminium.

The aluminium compounds of the present invention include electrically conductive intermetallic compounds which include aluminium. Electrical conductivity is an important property for a beam 18 to possess, since DMDs of the type discussed above require the application to their mirrors 12 via their beams 18 of electrical potentials. This requirement rules out the use of certain non-electrically conducting, though robust, materials for beams 18 such as SiO_2. As used herein, the term "electrically conductive intermetallic compound" means:-

An electrically non-insulative compound of aluminium and another material, which other material may be

(A) A metal, such as titanium, nickel, iron, niobium, tantalum, zirconium, molybdenum, tungsten, lithium, gold, calcium, copper, hafnium, magnesium, scandium, barium, strontium, ruthenium, chromium, vanadium, cobalt, iridium and rhodium, and including rare earth metals, such as cerium, gadolinium, holmium, lanthanum, lutetium, neodymium, samarium and terbium,

(B) A material which may be viewed as a metal or a non-metal, such as arsenic and antimony, or

(C) A non-metal, such as phosphorus, nitrogen, selenium, boron and carbon; and

(D) Mixtures of compounds set forth in (A).

Compounds meeting the above definitions, that is, electrically conductive intermetallic compounds having fewer primary slip systems than FCC include;

(1) Compounds which comprise aluminium and another metal--Al_2Au, Al_2Ca, Al_2Cu, Al_3Fe, Al_3Hf, Al_3Mg_2, Al_3Nb, Al_3Ni, Al_3Sc, Al_3Ta, Al_3Zr, Al_4Ba, Al_4Mo, Al_4Sr, Al_4W, Al_6Ru, Al_7Cr, Al_8V_5, Al_9Co_2, Al_9Ir_2, Al_9Rh_2, AlLi, Al_3Ti and AlTi;

(2) Compound semiconductors which include aluminium--AlSb, AlAs, AlP and AlN;

(3) Compounds which include aluminium and a rare earth--Al_3Ce, Al_3Gd, Al_3Ho, Al_3La, Al_3Lu, Al_3Nd, Al_3Sm and Al_3Tb; and

(4) Compounds which include aluminium and a non-metal--Al_2Se_3, Al_4C_3 and AlB_2. Mixtures of the sub-

ject intermetallic compounds include $Al_3Ti+AlN$ and $Al_3Ti+AlTi$.

Compounds which are preferred because of economic and functional reasons are Al_3Fe, Al_3Nb, Al_3Ni, Al_3Ta, Al_3Zr, Al_4Mo, Al_4W, AlAs, AlLi, AlN, AlP, AlSb, Al_3Ti, AlTi, $Al_3Ti+AlTi$ and $Al_3Ti+AlN$.

All of the foregoing compounds may be conveniently deposited by sputtering from a compound cathode or simultaneously from multiple cathodes. Either technique may be used to control or select the ratio of the constituents of the compound. Since the foregoing compounds contain significant or high aluminium content, the same or expediently modified etching materials and etch chemistries --etchants, masks or stops-- as used with previous aluminium and aluminium alloy hinges may, in general, continue to be used. For example, the appropriate conductive, ordered aluminium intermetallic compound may be sputtered to produce the layers 326 and 180 in the '049 patent, from which layers 326 and 180 the improved hinges 18 according to the present invention may be formed. No other radically significant changes to the processes described in the '049 patent are necessary to produce improved DMDs or other micromechanical devices the deformable beams of which do not experience significant relaxation or creep during many hours of use.

Claims

1. A deformable beam for a micromechanical device having a deflectable mass supported by the beam, and comprising:

   the beam being formed from one or more electrically conductive compounds having high melting points and exhibiting fewer primary slip systems than a face-centred-cubic (FCC) crystalline structure.

2. The beam according to Claim 1, wherein the beam is formed from an aluminium intermetallic compound.

3. The beam according to Claims 1-2, wherein the compound has the general formula;

   $$Al_XQ_Y$$

   where Q is a material selected from a group of materials containing; metallic elements, rare earth elements, non-metallic solid elements, non-metallic gaseous elements and combinations thereof.

4. The beam according to Claim 3, wherein;

   Q is a material selected from the group of materials consisting; gold, calcium, copper, iron, hafnium, magnesium, niobium, nickel, scandium, tantalum, zirconium, barium, molybdenum, samarium, tungsten, ruthenium, vanadium, columbium, iridium, rhodium, lithium, antimony, titanium, cerium, gandolinium, holmium, lanthanum, lutetium, nadolinium, terbium, selenium, carbon, arsenic, boron, phosphorus, nitrogen and combinations thereof.

5. The beam according to any preceding claim, wherein the beam is formed from a material selected from the group of materials containing; intermetallic compounds which include aluminium, compound semiconductors which include aluminium, compounds which include aluminium and a rare earth metal, compounds which include aluminium and a non-metal, and combinations thereof.

6. The beam according to any preceding Claim, wherein the beam is formed from a material selected from the group of materials containing;

   Al_2Au, Al_2Ca, Al_2Cu, Al_3Fe, Al_3Hf, Al_3Mg_2, Al_3Nb, Al_3Ni, Al_3Sc, Al_3Ta, Al_3Zr, Al_4Ba, Al_4Mo, Al_4Sr, Al_4W, Al_6Ru, Al_7Cr, Al_8V_5, Al_9Co_2, Al_9Ir_2, Al_9Rh_2, AlLi, Al_3Ti, AlTi, AlN, AlSb, AlAs, AlP, Al_3Ce, Al_3Gd, Al_3Ho, Al_3Lu, Al_3Sm, Al_3Tb, Al_2Se_3, Al_4C_3, AlB_2 and combinations thereof.

7. The beam according to any preceding claim, wherein the beam is formed by sputtering.

8. The beam according to any preceding claim, wherein the beam is formed from a material which is stronger and experiences less relaxation than aluminium or aluminium alloys.

9. The beam according to any preceding claim, wherein the beam is formed from a material which is electrically conductive.

10. The beam according to any preceding claim, wherein the micro-mechanical device is a spatial light modulator (SLM); and

    the mass supported by the beam is a mirror.

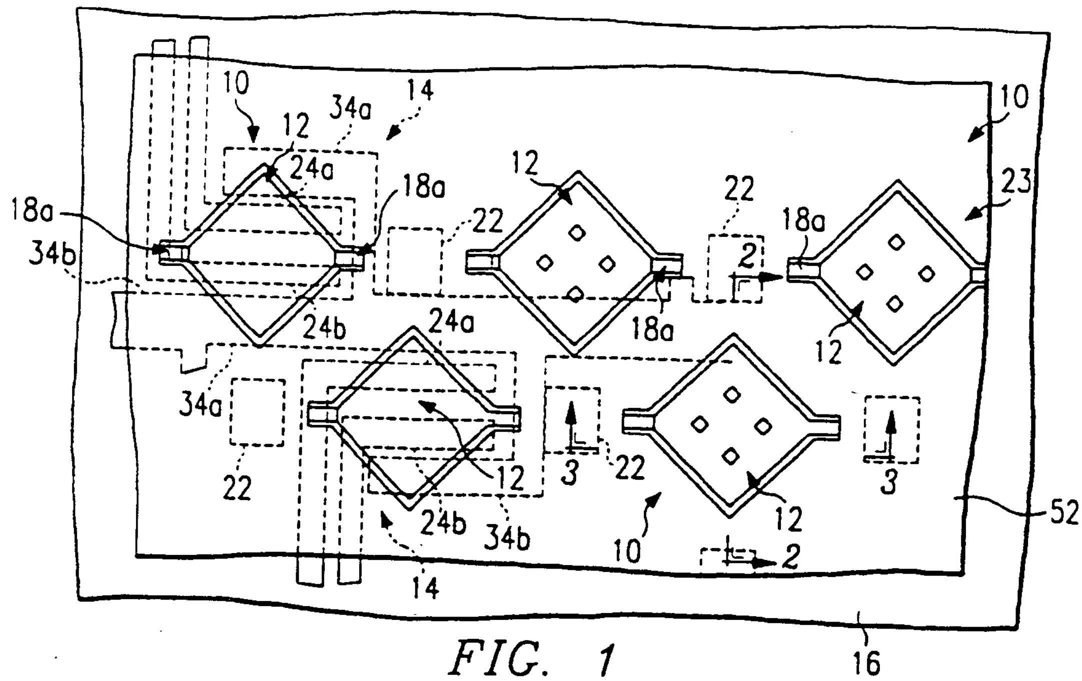

FIG. 1

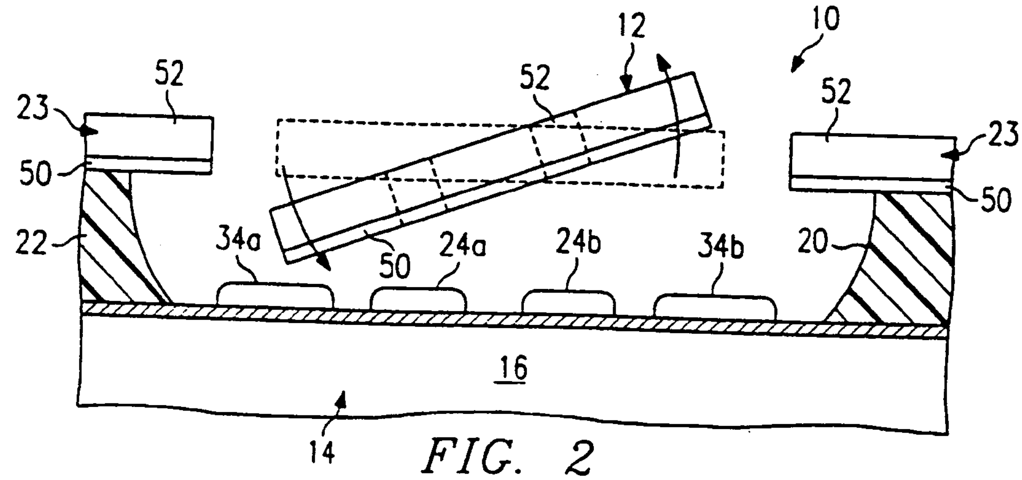

FIG. 2

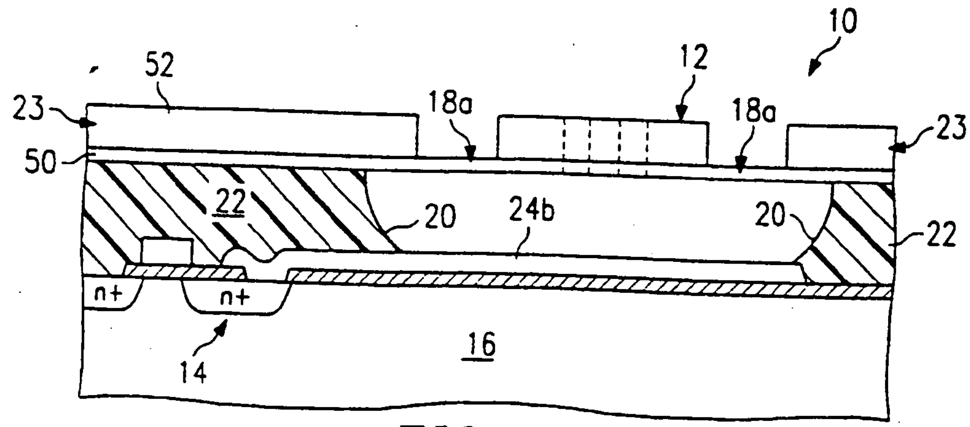

FIG. 3

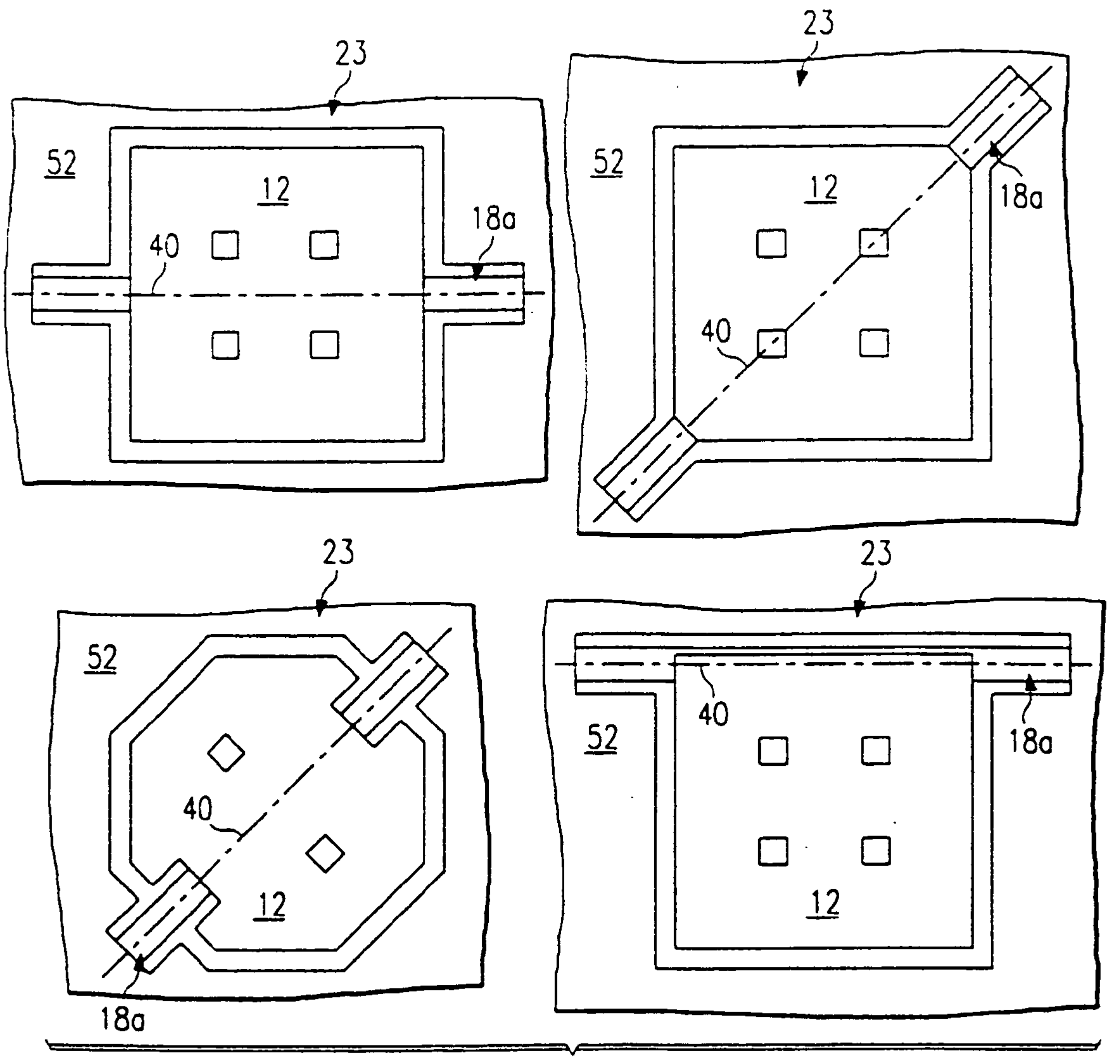
23
52
12
40
18a
23
52
12
18a
40
23
52
40
12
18a
23
40
52
18a
12

FIG. 4A

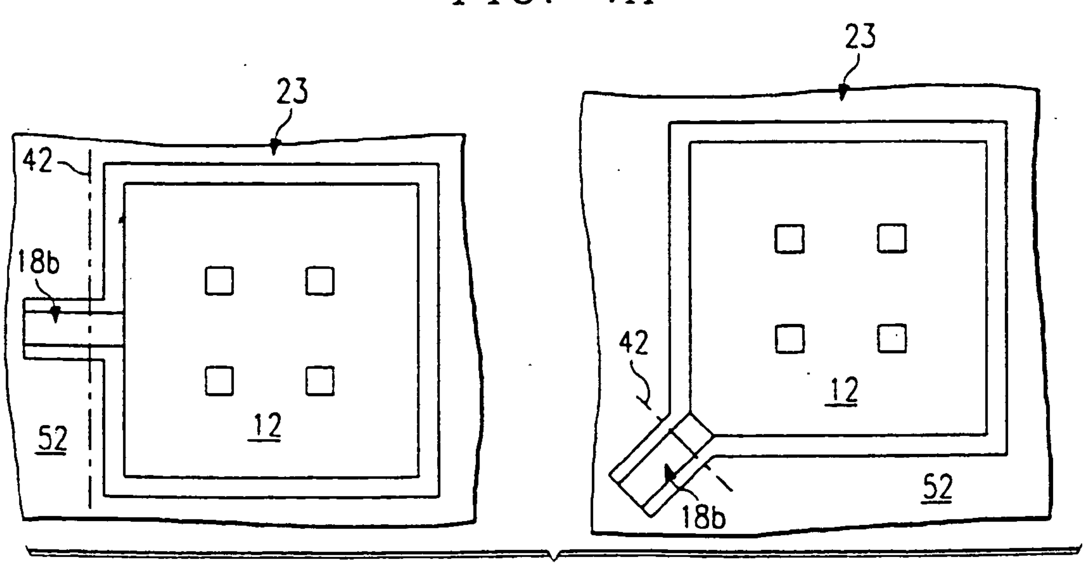
23
42
18b
52
12
23
42
12
18b
52

FIG. 4B

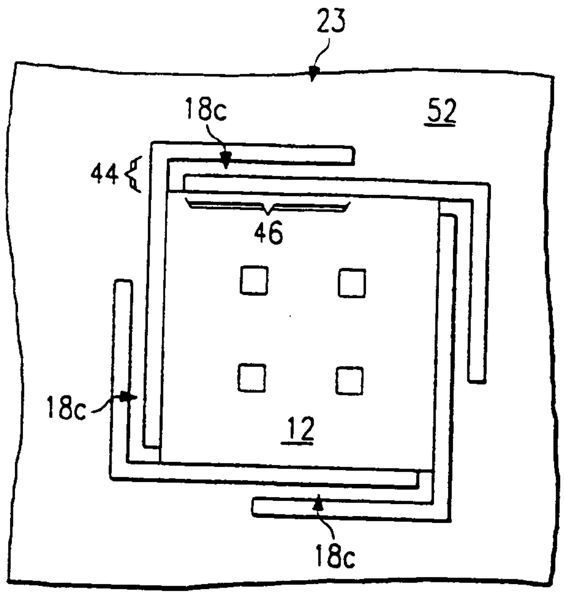

FIG. 4C

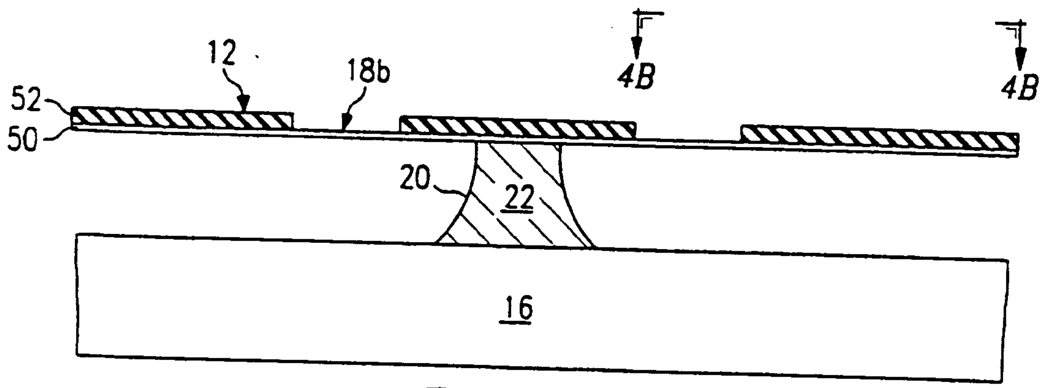

FIG. 5A

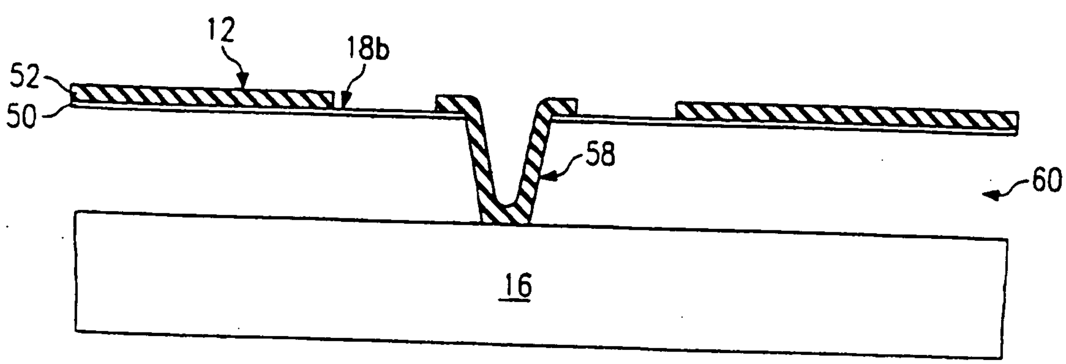

FIG. 5B